(39) In the case of propagation through a windy atmosphere I have not succeeded in proving that the flow of energy at the front of a wave is in the direction of the ray. The rate of change of momentum seems to be in this direction.

(40) **Stokes** *in* Phil. mag., London, April 1851. "Math. & phys. papers," v. 3, p. 142.

(41) **Pasquay** *in* Prometheus, 1903, **14**, p. 384.

(42) **Mohn, H.,** *in* Annalen d. Hydrographie, etc., 1892, 1893, 1895.

(43) **Livermore, W. R.** Report to the Lighthouse Board.

(44) **Capstick,** *in* Phil. trans., Royal soc., London, 1894, A., p. 1.

(45) **von der Borne, G.,** *in* Physikal. Ztschr., 1910, p. 483.

(46) **Humphreys, W. J.,** *in* Bull. Mt. Weather obsy., Washington, 1911, 4.

(47) **Quervain,** *in* Annalen, Schweiz. meteorol. Zentralanst., 1908.

(48) **Fujiwhara,** *see* (*16*).

(49) The conditions prevailing during the eruption of Mount Asama on January 6, 1911, and of Bandaisan correspond to those postulated by Henry. *See* first reference under (*16*), p. 41–44.

(50) **Desor,** *in* Fortschritte der Physik, 1855, **11**, p. 217.

(51) **Reynolds,** *in* Proc. Manchester lit. & phil. soc., 1873–4; Reynolds, Scientific papers, **1**, p. 43.

(52) **Hughes, T. McKenny,** *in* Nature, London, 1895, Nov. 14. Many other remarkable noises are described in letters to "Nature" in answer to a request by Sir George Darwin (Nature, London, 1895, Oct. 31) for information regarding the "barisâl guns" and "mistpoeffers." The former are described in the Proceedings, Royal Asiatic soc. Bengal, 1899, p. 199.

A number of papers on remarkable noises will be found in the Monthly Weather Review, Washington, vols. **23, 26, 31, 35,** between 1895 and 1907.

(53) **Sewell, C. J. T.,** *in* Phil. trans., 1911, **A210.**

(54) **Duhem,** *in* Annales de Toulouse, 1901–1904, (2), 3–5.

(55) **Le Roy,** *in* Comptes rendus, Paris, 1913, Ap. 21, 28, Je. 2; 1914, Ap. 27.

(56) This was first remarked by Kirchoff. *See* **Lamb,** Hydrodynamics, 2d ed., Cambridge, 1895, p. 587.

(57) Report of the U. S. Lighthouse Board, 1882, p. 163. In the Report of the British Association for the Advancement of Science for 1861, Prof. Hennessy discussed the subject and referred to some experiments made by Colladon on the Lake of Geneva in 1826.

(58) For the history of the subject, see: **Beazeley, A.** On phonic coast fog signals. Proc. Instit. civil engin., 1870–71, **32,** pt. 2.

(59) *See* **Henry's** Researches, p. 481, 489, 493, 497, 536, 546, 549; **Tyndall,** Sound, p. 298.

Johnson, A. B., *in* Bull., Phil. soc., Washington, 1881, **4,** p. 135; ibid., 1883, **5,** p. 23.

Livermore, Report, 1894; Nature, London, 1895, Aug. 8, p. 347; Knowledge, London, 1901, June.

(60) According to Price Edwards (Nature, London, 1902, May 29) the silent areas do not occur frequently. Mr. Della Torre suggested to me that they were due to the breaking up of the sound by local eddies or whirlwinds.

(61) **Tyndall,** *in* Proc. Royal soc., London, 1882, **34,** p. 18.

(62) **Fowle, F. E.,** *in* Nature, London, 1895, Nov. 7.

(63) **Rayleigh,** *in* Proc. Royal instit., London, 1902, **17,** p. 1; Nature, London, 1902, **66,** p. 42; "Scientific papers," **5,** p. 1.

(64) Tyndall gives a diagram of this siren trumpet in his "Sound." Numerous suggestions with regard to the most suitable pitch and location of a fog signal are given in Henry's Researches, in Livermore's report, and in the article "Lighthouses" in the Encyclopedia Britannica.

(65) **Henry,** Researches, p. 480; **Ribière,** International maritime congress, London, 1893.

(66) Encyclopedia Britannica, article "Lighthouses."

(67) **Rayleigh,** Scientific Papers, **5,** 1. A mushroom-shaped trumpet is often used on lightships.

(68) An account of these experiments on the Isle of Wight is given in Nature, London, 1902, May 29.

(69) **Flammarion.** The Atmosphere. London, 1873, p. 175.

(70) **Abbe, Cleveland.** Report, *in* Bull. Phil. soc., Washington, 1877, p. 139; **Peck, H. A.,** *in* ibid., 1907, **35,** p. 447.

(71) The possibility of interference was pointed out by E. Mach & B. Doss, and was regarded by them as an objection to C. Abbe's theory. (*See* Berichte, K. k. Akad. d. Wissensch., math.-physikal. Kl., IIA, Wien, 1893, 102.)

(72) **Boys, C. V.,** *in* Report, Brit. assoc. adv. sci., 1892; Nature, London, **47,** p. 415–420, 440–446.

(73) **Mallock, A.,** *in* Proc. Royal soc., 1907, **A79,** p. 262. Boys's experiments have also been discussed by **Stokes,** Memoir and scientific correspondence, **2,** p. 337–357.

(74) **Mallock, A.,** *in* Proc. Royal soc., London, 1907, **A80,** p. 110.

(75) See, for instance, **G. von Niessl** *in* Berichte, K. k. Akad. d. Wissensch., math.-physikal. Kl., IIA, Wien, 1896, **105,** p. 23, and 1912, 121_2, p. 1883.

In the case of the great meteor of September 23, 1910, O. Michalke heard about a dozen detonations of different strengths, two or three being very loud. Another observer heard a detonation like that of a distant gun followed immediately by a roll in the clouds, the sound appearing to come from an approaching region. The noise was quite different and much louder than that of thunder.

The noises mentioned by J. Burton Cleland and H. L. Richardson in letters to Nature, London, 1908, June 4 and August 27, were perhaps due to a meteor.

THE MECHANICS OF ATMOSPHERIC AIR WITHIN CYCLONES AND ANTICYCLONES.[1]

[Communicated to the International Meteorological Congress at Chicago, August, 1893.]

By Geh. Hofrat Prof. Dr. MAX MÖLLER.

[Dated Herzogl. Techn. Hochschule, Braunschweig, May, 1893.]

A. THE DIRECTION OF ROTATION AND THE DISTRIBUTION OF PRESSURE.

By a cyclone we understand a whirling mass of air whose rotation, in the Northern Hemisphere, is accomplished in a direction opposite to that of the movement of the hands of a watch; by an anticyclone, on the other hand, we mean a whirling mass of air whose rotation, in the Northern Hemisphere, corresponds to the movement of the watch hands.

In the Southern Hemisphere the conditions are reversed. In the center of the cyclone low pressure always prevails; hence the cyclone is often spoken of briefly as a depression. In the center of the anticyclone high atmospheric pressure generally prevails; hence this is often called a high pressure or maximum. However, there are also anticyclones with low pressure in the center; but this occurs only when the diameter of the anticyclone is small relatively to the strength of the wind (compare section 15 hereafter).

In the ultimate analysis the movements of the atmosphere are almost exclusively produced by differences of temperature; they are, however, so affected by the influence of the inertia of moving masses of air and so hindered by friction due to mutual mixing of masses of air that a study of these numerous relations must first be undertaken in detail before we can successfully proceed to the explanation of such complex natural processes.

According to the theoretical investigations of our master, the late Prof. Ferrel, in the field of the discussion of atmospheric whirlwinds, we have to distinguish many kinds of cyclones and anticyclones.

B. THE THREE KINDS OF CYCLONES.

(a) We have to mention first the cyclone with descending air and a cold center as it is presented to us in general in that whirl which surrounds the temperate, and partly also the cold zone, and produces the westerly trade, namely, the strong west winds of the "roaring forties."

Other examples of depressions with descending air currents have also been observed. Thus, for example, on April 13, 1893, two depressions of this kind rested upon western Russia and the Baltic Sea, respectively. The presence of descending air in this depression or cylone was shown first by the great dryness of the air and by the absence of any considerable precipitation, especially by the fact that clear sky prevailed in the region of the strongest winds; second, and most important of all, the circumstance that at more than 20 European stations at that time the northwest and northeast winds showed no inflow into the depression, but moved parallel to the isobars or passed from the region of feeble pressure over to that of higher.

[1] The present paper was prepared for publication in 1901, but publication has been delayed for the reasons stated in the REVIEW for February, 1914, 42: 93.

But these depressions were not wholly without cloud and precipitation, since by reason of friction on the rough ground the whirls in the lowest strata were enfeebled, and hence introduced a local flow of air into the depression and its ascent of air directly at the earth's surface up to moderate or at least slight altitudes. At the same time cloud and precipitation occurred in those portions of the whirl where for other reasons the air possessed a smaller wind velocity.

(b) Second must be mentioned those regions of cyclonic motion with decided descending currents that are distinguished by abundant precipitation and possess a more sharply defined center than the depressions mentioned under (a) and which when they show a small diameter can assume the form of tornadoes or waterspouts.

(c) Third, we mention the cyclones that have on one side ascending currents of air and on the other side descending.

C. THE THREE KINDS OF ANTICYCLONES.

(a) The anticyclones having *descending air currents* and high pressure in the center surrounded by isobars as nearly circular as possible, are surrounded by the ascendind air currents of cyclonic areas of depression whose masses of air flow overhead to the anticyclone in the anticyclonal manner.

(b) The anticyclones with *ascending air currents* rarely occur as depressions, but this can occur when they have small diameters.

More frequently anticyclones with ascending currents occur as areas of high pressure, and especially is this the case at the beginning, when the development of the anticyclones is in its first stages. In such cases the air flows anticyclonally toward the anticyclone from any depression in the lowest or median altitudes.

(c) The anticyclones with air currents *ascending on one side and descending on the other* but horizontal at the summit. An anticyclone of this character forms a zone of high pressure between two cyclones, one of which has ascending and the other descending currents of air at the center.

D. CURRENTS OF INFLOW AND OUTFLOW.

Those currents are designated as feeders that bring air to a cyclone or anticyclone. Those currents are designated as outflows that carry air away from the region under investigation. A storm that represents a region of outflow forms also a feeder for the neighboring regions. By means of the streams of inflow and outflow the moment of rotation of the whirling region becomes a cyclone or an anticyclone.

E. THE MOMENT OF ROTATION OF A MASS OF AIR IS INDEPENDENT OF THE MAGNITUDE OF THE GRADIENT.

In the following text the moment of rotation of any mass of air is taken with reference to the center of curvature of the isobars and to a system of axes at this central curvature and which move with the rotation of the earth's surface; hence we are ivestigating not absolute but relative air velocities, that is to say the winds.

It can not be made too clearly prominent that every whirl, whether of the cyclonal or anticyclonal form, when in contact with the rough surface of the earth loses some of the moment of rotation proper to it and that the loss thus arising can in no way be balanced by the work done by the gradient force.

The total work done by friction in the direction of the rotation of a whirl, or abstracted from the whirl, is expressed in the contrast of the amounts of the moment of rotation of the feeders and the outflows as soon as a steady condition of motion has been established. The rate of loss of moment of rotation per second induced by friction is equal to the difference of the quantities of the moment of rotation of the streams with reference to the center of the whirl, if we consider this latter as the center of the rotation.

If now the moment of rotation of the inflow, namely, the feeding streams, is of such eminent importance to the whirling system that it decides whether a whirl shall be a cyclone or an anticyclone; and if furthermore the work of the frictional resistances at the rough surface of the earth partially and steadily diminishes this moment of rotation, then we see the importance of those studies that have to do with these relations and with the motion of the upper currents of air.

Our subsequent investigations of these matters assumes a knowledge of certain auxiliary theorems of the theoretical doctrines of motion or dynamics which will now be enumerated and occasionally explained by applications.

F. THE MOMENT OF ROTATION WITH REFERENCE TO THE GRADIENT FORCE AND THE FRICTION.

AUXILIARY THEOREMS, GROUP I.

(1) The moment of rotation of any mass is not changed by the work done by the force due to the radial gradients. The demonstration of this theorem follows directly from the recognition of the fact that gradients are only the interior tension of the whirling system by which neither the center of gravity of the system is altered nor is the moment of rotation of the mass increased or diminished. From this there also follows directly the law of areas, or the law relative to the conservation of the moment of rotation whose application leads to the above theorem.

(2) The moment of rotation of a moving mass is diminished by the component of frictional resistance tangential to the direction of the circumference of the circle, namely, in the direction of the isobars.

(3) The effective force of a radial gradient can not again replace the loss of moment of rotation produced by frictional resistance, since according to Theorem (1), the effective force of a gradient can neither increase nor diminish the moment of rotation.

(4) In so far as a whirling system continually loses its moment of rotation by friction on the rough surface of the earth, but still continues its further rotation undiminished and therefore has a state of steady motion, it follows that a steady gain of moment of inertia coming from some other source compensates for the loss of moment of rotation due to friction. Now the system can receive no gain in moment of rotation, either from above out of the free interplanetary space or from below, and the forces due to the gradient are also excluded from consideration because they arise from the internal tension of the system, therefore we must recognize that the total work of friction which is done in the direction of the rotation, must be derived from the moment of rotation of the feeders themselves or the inflowing currents.

Applications under Group I.

(5) The large whirl of the temperate latitudes that gives rise to the westward trade, or is conditioned by it, and also attains a magnificent development in the

Southern Hemisphere suffers continual loss of rotary motion by reason of friction on the rough surface of the globe. The whole of this loss is entirely balanced by the moment of rotation of the feeders that flow inward as the upper westerly trades at high altitudes from the equator toward the polar regions. The work done by the meridional gradient force in this respect is zero if we examine it with mathematical exactness.

In so far as we must, in a special case, assume a velocity of zero for the wind component above the belt of high pressure in the direction of the circle of latitude, to that same extent must the whole whirl of the temperate and cold zones disappear; retarded by friction it must gradually come to rest or be broken up into regions of east and west winds.

(6) The living force or kinetic energy of the upper west trade or of its feeder is greater than the energy drawn from it by friction on the rough surface of the earth, because a part of the transferred energy is diffused by friction and mixture of masses in the overlying layer of air; that is to say, it is converted into heat.

On this point extensive investigations are at hand in the department of hydromechanics or the movement of water in rivers. For example, it is known that in deep streams scarcely one-third of the living force, or kinetic energy, communicated per second to it through the work done by gravity is in that same time destroyed by friction at the bottom of the stream; more than two-thirds of this increase in living force is dissipated in the water itself; that is to say, converted into heat (1).

In the second memoir (1) it is shown that the friction R at the ground is to be computed not from the work done per second by the force of gravity but by the quantity of motion communicated per second by the force of gravity (*i. e.*, the mass, m, multiplied by the increase, Δv, per second in velocity) or on the other hand, by the increase per second of the moving mass, Δm, multiplied by its velocity, v, so that we have the formula

$$R = v\Delta m.$$

Applying this formula to whirling motions we replace the quantity of motion by the moment of rotation and have

$$Rr = vr_1\Delta m$$

or, since r is variable because the friction affects every circular zone within the whirl, we have

$$\int dR.r = vr_1\Delta m.$$

In the application of this formula it is to be remembered that a steady condition of motion is assumed, that Δm indicates the mass added by the feeders per second, v is the component of the velocity of the feeder in the direction of the west wind, and R the friction in kilograms that the west wind experiences per unit element of the surface of the base of the whirl. This equation further assumes that the outflowing stream has no moment of rotation.

In so far as the outflow, *i. e.*, the return stream toward the hot zone, also appears in the form of a west wind or in our hemisphere a northwest wind, and in so far as there also occur in the cold zone local easterly winds for which we have to substitute the negative sign before the wind velocity we arrive at the following general theorem:

(7) In steady motion the difference between the moments of the momenta of the inflowing and outflowing streams is equal to the difference of the moments of friction produced by west and east winds within the system under consideration.

The following equation holds good:

$$\Delta m_1 v_1 r_1 - \Delta m_2 v_2 r_2 = \int dR_1 r - \int dR_2 r.$$

In this equation $\Delta m_1 v_1 r_1$ indicates the moment of the momentum of the feeder which brings the small mass Δm_1 per second within the whirl and adds it to this system. The quantity $\Delta m_2 v_2 r_2$ represents the moment of the momentum of the outflowing stream in so far as this has the same direction as the moment of the inflowing stream. If the outflow rotates with the earth as an east wind, while the inflow blows as a west wind, then the sign changes from minus to plus. The expression $\int dR_1$ gives the moment of friction of the west wind; the expression $\int dR_2 r$, gives the moment of friction for the east wind.

For systems the centers of whose whirls do not lie at the pole we substitute in the place of west or east wind the component of motion of the rotation to the right or left around the center of the whirl of the system.

(8) In so far as no moment of rotation is communicated to a system by the difference of the moments of the quantities of motion of the inflowing and outflowing currents, because the feeders show no whirl or the influence of the two currents annul each other, it follows that so far as a permanent steady condition is brought about the influence of the friction on their moments is nothing.

Therefore we have the following equation:

$$0 = \int dR_1 r - \int dR_2 r.$$

In this case the whole system is to be considered as divided into regions of opposite rotations whose moments of friction are equal to each other but have opposite signs. The whole atmosphere is subject to this condition as regards the east and west winds and so far as small cosmic influences, as yet unknown to us, do not introduce variations in the moment of momentum of the whole terrestrial atmosphere.

During this steady condition the moment of friction of the east winds for the whole earth is equal to the moment of friction of the west winds. On this point Ferrel (2) says:

"It is evident, however, that the east and west motions of the atmosphere at the earth's surface must be such that the sum of the resistances of each part of the earth's surface multiplied into its distance from the axis of motion must equal 0, else the velocity of the earth's rotation * * *."

(9) The location of the belt of high pressure that separates the region of east and west trade winds, according to theorem (8) is dependent to a very great extent on the distribution of land and water. If in the neighborhood of the pole there occur an extended continent, where therefore the earth's surface is rough, then the region of high pressure moves nearer the poles. Asia presents an example of this shifting.

If a rough surface occurred only in the neighborhood of the pole, while the rest of the earth's surface is quite smooth, so that frictional resistances were excluded from consideration in lower latitudes, then in this special case the region of east winds would extend from the equator to the neighborhood of the pole and cover also the border of the rough polar surface. At the pole itself and above the rough land surface there would form a small cyclone of west wind. Almost the whole mass of the atmosphere would flow to the pole.

The oft-repeated attempt to compute the location of the zone of high pressure between the east and west trades without knowing the effect of friction is a labor that has no prospect of success. It is not to be encouraged, has led to very deceptive conclusions, and quite confused such readers of this class of memoirs as have not yet deeply studied the nature of the problem. The works of Werner von Siemens, although they should be thankfully accepted as stimuli, have unfortunately operated in this injurious manner. Notwithstanding the imperfect presentations and numerous erroneous conclusions contained in his memoirs, they still have permanent value on account of many correct fundamental ideas.

(10) Were the whole surface of the earth in general perfectly smooth, nevertheless a narrow zone of rough land area extending around the earth in but one hemisphere or even one single island existing therein, would suffice to determine the distribution of the regions of cyclonic and anticyclonic atmospheric motions over the whole surface of the earth.

(11) The theorems here deduced for the general circulation of the atmosphere also hold good, without great changes, for all smaller cyclones and anticyclones.

(12) If the equatorial zone were rough, but the remaining surface of the earth perfectly smooth, then almost the whole mass of the atmosphere would draw toward the equator, the pole being left almost wholly free from air. The belt of high pressure would almost coincide with and be narrower than the zone of rough land. The form of the atmosphere would approach that of Saturn's ring.

G. THE FORMATION OF THE GRADIENTS DEPENDENT ON INERTIA.

AUXILIARY THEOREMS, GROUP II.

(13) Air that moves freely in an inertia curve deflects neither to the right nor to the left from its orbit and therefore produces no pressure gradient perpendicular to the direction of its motion.

(14) Air currents that are forced to deviate to the right from their inertia paths produce higher pressure on the left hand or a pressure gradient directed toward the right perpendicular to the inertia path; conversely for deflection to the left the pressure gradient is directed to the left.

Applications under Group II.

(15) The inertia path shows in the Northern Hemisphere a deviation to the right whose value per second in $2w \sin \phi$, so that in $12 \frac{1}{\sin \phi}$ hours a curve somewhat like a circle will be described.

The following equation holds good,

$$2r\pi = v \times 12 \times 3600 \frac{1}{\sin \phi}$$

in which r indicates the radius of curvature of the curve of inertia, and v the wind velocity [i. e., relative to the earth's surface. EDITOR.]

$$r = \frac{v}{\sin \phi} \cdot \frac{12 \times 3600}{2 \times 3.14}$$

$$r = \frac{6880}{\sin \phi} \cdot v$$

For $\phi = 50°$ and $\sin \phi = 0.766$ we have $r = 8860v$, whence are derived the values,

when $v = 1$ meter, $r = 8.86$ kilometers.
when $v = 10$ meters, $r = 88.60$ kilometers.
when $v = 50$ meters, $r = 443.0$ kilometers.

When a wind of 1 meter per second velocity is forced to describe an anticyclonal path whose radius of curvature is smaller than 8.86 kilometers—or when a 50-meter wind is forced to describe a path whose radius is less than 443 kilometers there occurs the remarkable fact that in the center of the anticyclone a diminution of pressure is established. In this case the anticyclone becomes a barometric depression.

Local whirls, waterspouts, and many tornadoes offer examples of this sort of depressions—in which the rotation of the air is occasionally anticyclonal.

It is also to be remarked that in consequence of deviations of currents from the inertia path, all gradients at any altitude whatever possess full activity upward and downward. On the other hand, a storm occurring at any altitude in general and also at the bottom of the atmosphere will produce no gradient perpendicular to its movement when the air within it follows an inertia path undisturbed.

(16) The stronger the wind blows anticyclonally in a region of high atmospheric pressure, by so much the larger is the minimum radius of curvature of the isobars of that anticyclone.

(17) When the radius of curvature of the central isobars of an anticyclone with high pressure in the center, is zero it presupposes calm (in that region). Therefore near the central part of a high-pressure anticyclone calms prevail, for when calm does not prevail in the center of the anticyclone there arises there a low-pressure anticyclone, i. e., a depression with anticyclonal movement.

H. ON CONTRACTION AND DIVERGENCE OF WIND CURRENTS.

AUXILIARY THEOREMS, GROUP III.

(18) A current of air that suddenly passes from a region of strong gradients into a region of feeble gradients describes approximately an inertia-path in this passage. At the same time the gusts of wind previously parallel begin to describe convergent paths, so that in the midst of the current there is an accumulation of air and an increase of pressure as expressed by a zone of higher pressure that stretches along the axis of this stream. Furthermore, in the inner portion of the anticyclonal whirl there arises a diminution of pressure, a depression of the kind described in paragraphs (14) and (15).

(19) In so far as by the passage into regions of other gradients, the resulting deviations of the wind paths occur simultaneously, i. e., equally early, there arise contractions with the phenomena described in paragraph (18). But in so far as for a deviation toward the left, the left-hand jet is first deviated and the jets on the right hand of it, parallel to it deviate subsequently, there arise divergent rays that produce a groove of low pressure along their axes.

Applications under Group III.

(20) On the front of a depression advancing from west to east there blows a strong south wind. By the progress of the depression eastward the gradient changes (at any point) with the passage of the depression; in the Northern Hemisphere the gradient on the right-hand front of the depression turns toward the right hand. Near the center

of the depression this turn takes place with a greater velocity than corresponds to the expression $2w \sin \phi$. Consequently the wind that previously blew from the south completes a turn to the right that is completed quicker than corresponds to the inertia-path. In this act there occurs the contraction phenomena described in section (18). The change of barometric pressure clearly shows the advance of the zone of pressure that must form at the point and the movement change in direction of the wind. Here occurs the well-known sudden rise of pressure of from ½ to 2 millimeters which is observed at every sudden change in direction of the wind in the direction of the curve of inertia and especially during thunderstorms. The air thus temporarily compressed below expands upward and favors the formation of sudden heavy rainfalls of short duration.

In this special case the phenomena here described are intensified by the relations mentioned in section (19), especially because the deviation to the right here of the left-hand streamers first and the right-hand last increases the convergence of the jets.

The meaning of the convergence and divergence of the upper and lower winds is reported on in the work: "Beziehungen, etc., [Relation between the upper and lower winds of a depression and the cloud forms resulting therefrom]" in Annalen der Hydrographie und maritimen Meteorologie, Jhrg. 1882, Heft iv, Berlin.

Similarly it has been shown that the behavior of the electric and magnetic attractive and repulsive forces is to be referred back to the results that arise when wave-like rays possess diverging or converging directions. By the study of these processes there opens up to us a clear view of the dynamic properties of the etherial forces known as electricity and magnetism. Thus that elastic strain that Farraday and Maxwell recognized by its effects as a process in space, but which had not yet been analyzed into its details, is now set forth before us.

The final results agree exactly with the results deduced by Maxwell—these deductions are given by me in my book (3) on electricity and magnetism.

Theoretical physics has hitherto given but little attention to the phenomena of suction and obstruction in fluid motions but these processes are of the highest importance in studying the relations existing between dynamic and static pressure, and that, too, as much so in reference to the movements of material systems as in movements of the ether itself.

Of course, it is known to me that other theories have also been advanced endeavoring to explain the temporary rise of the pressure during thunderstorms and on the occasion of sudden changes in the direction of the wind, but I believe that I can refute all such theories so far as they are as yet known to me.

(21) The upper winds flowing poleward at great altitudes from the lower latitudes, are in their progress subject to the deflecting force of the earth's rotation, which at first at the equator has the value of zero. These upper winds move under conditions similar to those for the south wind described in section (20), only in this case it is the poleward progress of the current in the higher latitudes that causes a bend in the inertia path, thereby producing a convergence of the currents. The accumulation thus produced in consequence of the convergence of the inertia-curves develops upward and, in opposition to the conditions described in section (20), now causes a compensating current directed downwards, corresponding to the rainless weather of the dry zone.

These processes are described by me in the memoir "Ueber den Kreislauf atmosphärischer Luft zwischen niederen und höheren Breiten [The interchange of atmospheric air between lower and higher latitudes.]" (Aus dem Archiv der Deutschen Seewarte, Vol. X, 1887, No. 3) and especially on pages 14 and 15 of that memoir are these submitted to a special computation. A short extract from this memoir is also given by Frank Waldo, in his work "Modern Meteorology," on pages 311–315 with a plate.

E. Herrmann's notice of my analysis (Met. Ztschr., April, 1893, 10. Jhrg., p. 132) is, unfortunately, misleading. He substitutes the convergence of the meridians for the convergence of the inertia-curves. The former acts in the same direction but much more feebly than the latter. He has not appreciated the finer points of my investigation.

I. PROCESSES THAT DO NOT CORRESPOND TO THE STEADY CONDITION.

AUXILIARY THEOREMS, GROUP IV.

(22) In so far as an outflow above and an inflow below is set up within a previously quiet region by means of a warming at the central region, C, there is formed a cyclone below and an anticyclone above, but the latter immediately forms an eye at the center above C, where cyclonal motion has been established. Therefore the upper anticyclone forms only a ring in whose interior a cyclone occurs, which latter expands in proportion as air rises from below to the top, and is endowed with cyclonal motion and imparts cyclonal rotation to the upper layer. In this connection the gradients (of pressure) do not work, they are directed only toward the moment of rotation. (See theorem No. 1.) The upper ring of air endowed with anticyclonal motion, widens and wherever it passes over a region on the earth it temporarily influences the weather and the wind.

(23) When a depression coming from the ocean turns toward a continent, the whirl will in its lower part be enfeebled by the roughness of the land. At once there develops within the depression an active inflowing and ascending current of air, so that heavy precipitation falls. Furthermore, cold air is often carried upward in this case, whereby the depression receives a further enfeeblement or even complete dissolution.

(24) In the development of a region of high pressure the air must flow inward anticyclonally, by reason of which the anticyclone should show a longer duration than the cyclone. The anticyclonic feeder can flow into the anticyclone either above, from a depression with ascending air currents, or below from a depression with descending air currents. In the latter case, this process of the development of the anticyclone is connected with precipitation.

(25) In so far as the column of air cools at the center C, the upper air flows cyclonally from all sides toward the center C. On the other hand, a region of high pressure develops below in proportion as the upper air flows inward; furthermore, there develops below an anticyclonal outflowing movement of the air. The upper cyclone that has developed above the anticyclone, extends downward to the lower strata in proportion as the lower anticyclonal-moving air flows away and is replaced by air in cyclonal motion. The area of high pressure in the anticyclone flattens out and local depressions form where

the air descends most decidedly from the upper layer. The anticyclone is now arrived at the process of dissolution.

K. CONCLUSION.

(26) The literature of the past 10 years [1883–1892] contains numerous expressions of opinion that are opposed to the laws of atmospheric motion; we may infer that the readers have thereby been led into error.

Too seldom do the mathematicians describe the process that they propose to submit to calculation. The whole presentation of the subject under computation may be erroneous or at least imperfect. The reader is not always able to determine to what extent the results of the computation have practical applications. For instance, Ferrel has not especially, in fact scarcely at all, considered the fact that the upper and lower strata of the atmosphere accomplish an equilibration of their moments of inertia by reason of a continuous steady mixture of their masses steadily as well as periodically renewed.

Again, the result that the belts of high pressure that inclose the hot zones ought to occur in the neighborhood of latitude 30° arises from an arbitrary assumption as to the magnitude of the total moment of rotation of the whole atmosphere, that is made even before the beginning of his analysis.

It is to be considered that the transportation of a kilo gram of air from the region of the pole to that of the equator or conversely, assuming the velocity of the wind to be zero at the beginning and the end of the transfer, expends an amount of work or absorbs an amount of work equal to about 20,000 kilogram-meters; so that the air coming from the equator transfers its kinetic energy or its moment of rotation to the air flowing in the opposite direction, either by direct processes of mixture of masses, or by means of friction on the rough ground in the cyclones and anticyclones, and therefore by the tension from west to east arising from the reaction between the ground and the air. In Ferrel's theories the very important processes of mixture of masses and the interchange of moments of rotation are scarcely mentioned, and therefore Ferrel's theoretical deductions give such large wind velocities and such slight values of the atmospheric pressure at the poles.

The solution of problems in dynamic meteorology are still always merely partial solutions that are only applicable between definite limits and under special assumptions. Therefore the numerical values thus obtained should not be considered, either by the mathematicians or the reviewers, as "refined gold" since thereby the theory would be brought into discredit.

Empiricists are inclined to reject not only the recognized imperfect numerical results of any theory, but also the good ideas on which these are based.

Hitherto theory has dealt too little with numerical results; we have been satisfied with the deduction of formulæ and therefore have not learned the useful applications of theory so quickly as would have been attained by more frequent execution of numerical calculations. In general, meteorologists themselves do too little observing. They know only so much of the weather processes as the observers communicate and important details remain unrecognized. No clear connected view of the weather processes can be obtained in this way.

The details of the theory of vortex motions, so far as they have been thoroughly developed in mechanics for the construction of turbines and centrifugal pumps and blowers, are too little known to meteorologists. At the present time we frequently find in meteorology efforts to establish new theoretical relations that have already been expounded with perfect clearness in practical mechanics.

Again, the theory of the processes of suction and obstruction ("Stau- und Sauge-Vorgänge") are not sufficiently studied by meteorologists and physicists, nor the conditions, circumstances, and extent to which work is performed or prevented in the atmosphere.

From the above exposition it follows that the mechanics of cyclones and anticyclones stands in close dependence on the work of the late eminent mathematician, William Ferrel; but can now be best furthered by simultaneous thorough consideration of the processes in space (viz, geographic) and by personal observation of all the details of the weather phenomena as found by studying the important synoptic weather charts and telegraphic weather reports.

Personal studies of this kind are, however, prevented by want of time and the modern system of the subdivision of work. Especially does the latter make it difficult for a single person to attain a general oversight of the whole subject. A subdivision of work is indeed demanded in the interests of a successful service in every meteorological institution; however, it should not be pushed so far that a meteorologist is prevented from the execution of personal observations or is robbed of the time needed to enable him to become well grounded in theoretical researches.

At the present time the development of the science of meteorology is directed too strenuously toward the subdivision of labor. We imagine that by the increase of ordinary observational data we may gain a general oversight of the subject. In reality, the labor applied to ordinary statistics and the conduct of the general service is thereby so greatly increased that there is no time or thought left for the practice of independent higher studies. One's interest is too much diverted from the consideration of the weather phenomena as a whole, and also from important details, such as the observation of the clouds and the method of formation of falling rain.

These defects, due to the unavoidable necessity of the subdivision of labor, are only to be overcome by the freest personal interchange of views, in order that the labors of many assistants may be made most profitable and productive by practically skillful, well-directed, and liberal-minded administration.

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(2) **Ferrel, Wm.** Meteorological researches for the use of the Coast Pilot. Part 1: On the Mechanics and general motions of the atmosphere. Washington. 1877. p. 42, par. 38. f°. (U. S. Coast survey. [Publication])
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THE HALOS OF NOVEMBER 1–2, 1913.

[Translated from Annuaire, Soc. météorologique de France, mai, 1914.]

Mr. Louis Besson offered a communication [May 5, 1914] on the oblique arcs of the anthelion. This phenomenon, one of the rarest connected with unusual halos, has been seen two days in succession in the United States, November 1 and 2, 1913.